Summary

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Day 1:

- Philosophy and Process
  - Performance-based retrofit: upper and lower level earthquakes
  - Seismic Retrofit Categories
  - Screening, Evaluation and Retrofit (Strategies, Approaches and Measures)

- Category A and B bridges
  - Screening
  - Evaluation
  - Retrofit measures
    - Seats, bearings, superstructures
Days 2 and 3:

- **Category C and D bridges:**
  - Requirements
  - Screening
  - Evaluation
    - Structural modeling, demand & capacity assessment
    - Geotechnical modeling and capacity assessment
  - Substructure retrofit measures (columns, abutments, footings, and foundations)
  - Site remediation, hazardous sites

Collapse of Shi-wei bridge due to liquefaction, Chi-chi Earthquake, Taiwan, September 1999
Shear failure in pier of Wu-shi bridge, Chi-chi Earthquake, Taiwan, September 1999
Performance-based retrofit

- Explicit attempt to satisfy public expectations of bridge performance for earthquakes ranging from small to large... for example:

<table>
<thead>
<tr>
<th>Performance</th>
<th>Earthquake</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small</td>
</tr>
<tr>
<td>No interruption</td>
<td>✓</td>
</tr>
<tr>
<td>Limited access</td>
<td></td>
</tr>
<tr>
<td>Closed for repairs</td>
<td></td>
</tr>
</tbody>
</table>

![Relative Effort vs Hazard Level Diagram](image)

- [Relative Effort vs Hazard Level Diagram](image)
Information required to determine *seismic retrofit category*

- Anticipated Service Life
- Performance Objectives
- Bridge Inventory
- Seismic Hazard
  - Ground motions
  - Site effects

Seismic retrofit category

**Seismic Hazard Level (SHL)**

- Bridge Importance
- Anticipated Service Life, ASL
- Spectral Accelerations, Ss and S1
- Soil Factors, Fa and Fv

**Performance Level (PL)**

**Seismic Retrofit Category (SRC)**
Seismic retrofit category

<table>
<thead>
<tr>
<th>HAZARD LEVEL</th>
<th>PERFORMANCE LEVEL</th>
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<tbody>
<tr>
<td></td>
<td>PL0: No min.</td>
</tr>
<tr>
<td></td>
<td>PL1: Life-safety</td>
</tr>
<tr>
<td></td>
<td>PL2: Operational</td>
</tr>
<tr>
<td>I</td>
<td>A</td>
</tr>
<tr>
<td>II</td>
<td>A</td>
</tr>
<tr>
<td>III</td>
<td>A</td>
</tr>
<tr>
<td>IV</td>
<td>A</td>
</tr>
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</table>

Minimum requirements

<table>
<thead>
<tr>
<th>ACTION</th>
<th>SEISMIC RETROFIT CATEGORY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td>Screening/Retrofitting</td>
<td>NR</td>
</tr>
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</table>
Screening and prioritization

*Purpose is to screen an existing inventory of bridges for seismic deficiencies and prioritize the inventory for seismic retrofitting based on vulnerability, hazard, and other factors.*

*Screening methods are expected to be quick and thus conservative; bridges that ‘fail’ are passed to a second level of screening i.e. ‘detailed evaluation’*
Methods of evaluation

In general, all evaluation methods involve (figure 1-13):
- Demand analysis
- Capacity assessment
- Calculation of a capacity / demand ratio either
  - for each critical component in a bridge or
  - for bridge as a complete system

Exceptions exist

Methods of evaluation continued

Three categories, six methods:

I. No demand analysis
   1. Method A1/A2 (capacity checks made for seats and connections)
   2. Method B (capacity checks made for seats connections, columns, and footings)

II. Component C/D evaluation
   3. Method C (elastic analysis: uniform load method, multimode spectral analysis; prescriptive rules given for calculation of component capacity)
**Methods of evaluation continued**

**III. Structure C/D evaluation**

4. Method D1 (*capacity-spectrum method*: elastic analysis for demands, simplified models for calculation of capacity);

5. Method D2 (*pushover method*: elastic analysis for demands, nonlinear static analysis used for calculation of pier capacity);

6. Method E (nonlinear time history analysis for calculation of both demand and capacity)

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**Geotechnical modeling**

- Geotechnical Modeling and Capacity Assessment
  - Foundation Modeling
    - Shallow footings
    - Piles and pile groups
    - Abutments
  - Ground Displacement Demands
    - Settlement
    - Liquefaction Induced Lateral Spreads
Retrofit strategies, approaches, and measures

**Retrofit Measure**: a device or technique such as a restrainer, column jacket, stone column.

**Retrofit Approach**: One or more measures used together to achieve an improvement in performance such as strengthening using restrainers and jackets...

Retrofit strategies, approaches and measures continued

**Retrofit Strategy (one of the following)**:
- One or more approaches used together to achieve desired level of improvement in performance such as strengthening and site remediation.
- Partial or full replacement
- Do-nothing (retrofitting not justified)
Retrofit approaches

**Approaches:** one or more measures to achieve:
- Strengthening
- Displacement capacity enhancement
- Force limitation
- Response modification
- Site remediation
- Partial replacement
- Damage acceptance or control

Retrofit matrix

For a given seismic deficiency, matrix identifies possible *approaches,* and for each approach, matrix recommends possible *measures* for consideration
Retrofit matrix: approaches/measures

<table>
<thead>
<tr>
<th>Deficiency</th>
<th>Retrofit approach</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strengthening</td>
</tr>
<tr>
<td>Unstable footings</td>
<td>10.3.2 10.4.2</td>
</tr>
</tbody>
</table>

Retrofit measures

- **Superstructure measures:**
  - Restrainers
  - Seat width extensions, catcher blocks
  - Continuous simple spans
  - Bearing side-bar restraints, shear keys, stoppers
  - Isolation bearings and energy dissipators, including ductile-end-diaphragms
Retrofit measures continued

- **Substructure measures**
  - Column jacketing, using steel, fiber composites, or concrete shells
  - Infill walls
  - Column replacements

Retrofit measures for foundations and hazardous sites

- **Retrofit Measures for**
  - Abutments, Footings and Foundations
  - Hazardous sites including
    - near active faults
    - unstable slopes
    - liquefiable sites.
Thanks!

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- Rick Nutt, Consultant
- Jane Stoyle, MCEER

Thanks!

- Phil Yen, FHWA
- Glenn Smith, FHWA